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TITLE HOLDUP COUNTERS FOR THE PLUTONIUM FUEL PRODUCTION FACILITY--PFPF

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HOLDUP COUNTERS
FOR THE PLUTONIUM FUEL PRODUCTION FACILITY--PFPF*

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ABSTRACT

A neutron coincidence counting system has been developed for assaying plutonium holdup in glove boxes at the automated mixed-oxide fuel fabrication facility, PFPF, in Japan. The time-correlated neutron emission rate arising from the spontaneous fission decay of plutonium isotopes is measured and converted to grams of plutonium contained in the glove box. Each detection system consists of a pair of polyethylene slabs containing ^{3}He proportional counters and associated electronics. These slabs are placed on either side of the glove box that is to be measured for plutonium holdup. The detectors are moved by a portable lifter to map out the coincidence response from the entire glove box. Results of a design optimization study that considered detector efficiency, as well as overall size and weight and how these parameters interface with the procedure of mapping the glove box, are presented. The use of the Los Alamos transport code, MCNP, in the detector design optimization and in the aid of calibration is also discussed.

INTRODUCTION

Material Accountancy

For inspection and inventory control at plutonium fabrication facilities, it is necessary to measure a significant fraction of the plutonium present. At larger facilities, the inevitable accumulation of residual plutonium contained in process equipment, or process holdup, presents a material accountancy and verification problem because it is normally not measured. It would therefore be desirable to measure this material. Such measurements are difficult to perform in general, primarily because of signal variations as a result of geometric and attenuation effects. Nondestructive measurements could potentially be made using either gamma-ray or neutron based techniques. Gamma-ray methods have been developed that are applicable to relatively small holdup masses and require the estimation of self-attenuation losses. As the plutonium mass increases, gamma-ray methods become impractical because these self-attenuation losses become too large to correct accurately. Attenuation as a result of the process equipment adds to this problem. Neutrons are more penetrating than gamma rays and are therefore better suited for measuring large masses surrounded by bulky equipment. In either method, geometric effects present a challenge for detector calibration.

The Plutonium Fuel Production Facility (PFPF) presents a favorable case for the application of holdup measurements primarily because the plant is automated and the in-process plutonium is remotely stored. As a result of this automation, material tends to be more localized, and all in-process materials can be removed to the shielded intermediate storage during measurement of the holdup in the glove boxes. Both of these aspects benefit an assay. Neutron coincidence[1] counters, called glove-box assay systems (GBAS), have been developed that enable the process holdup to be measured in situ without special clean-out procedures before the assay. These detectors measure the time-correlated neutron emission from the even isotopes of plutonium and provide a measure of the total amount of plutonium when combined with the isotopics of the sample. Three identical pairs of slab detectors will be installed and calibrated in June 1990 at PFPF. The identical nature of the slabs provides redundancy, and having multiple units allows for easy access to the three production process areas. Monte Carlo neutronic calculations were performed simulating the detector response to optimize the design and refine the measurements.

DETECTOR DESIGN AND DESCRIPTION

Design considerations are centered primarily on obtaining maximum efficiency with a minimum weight and characterizing the response profile. Figure 1 is a schematic top view of a typical glove box/detector arrangement. The two slab detectors are positioned on either side of the glove box and move in unison to map out the coincidence response from the plutonium residing in the glove box. A leaded Plexiglas shield is part of the glove-box arrangement that serves to provide shielding from low-energy gamma rays. Because the shield has a high hydrogen content and does not contain a neutron poison, it thermalizes neutrons so they can be captured by the ^{3}He proportional counters that are embedded in the high-density polyethylene detector slab. The Los Alamos transport code MCNP[2] simulated the glove box, Plexiglas shield, and detector in the effort to incorporate the existing shield into the detector design. The moderation provided by the Plexiglas shield allowed the detector slab to be only 7.6 cm thick for optimum efficiency compared to 10 cm for a slab detector without the Plexiglas shield. This reduced thickness results in a substantial weight reduction without loss in detector performance.

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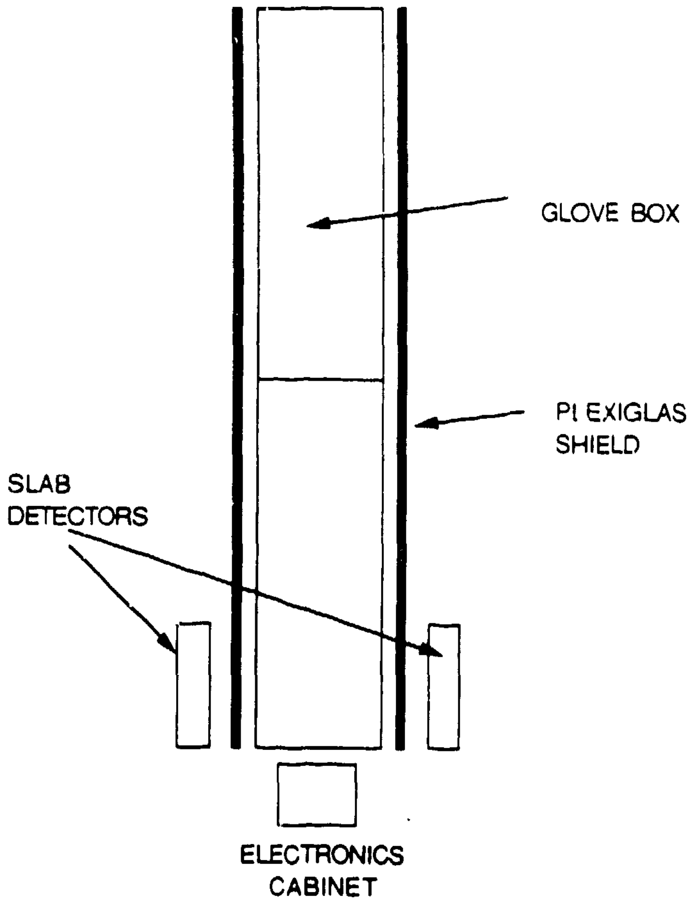

Fig. 1. Schematic top view of glove box, leaded Plexiglas shield, and slab detectors.

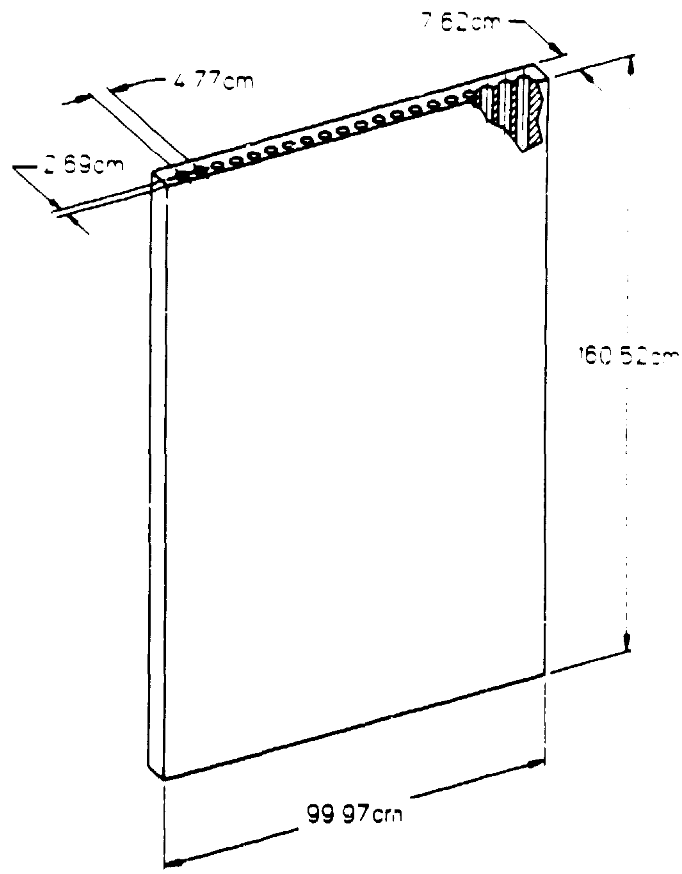

Fig. 2. Sketch of slab detector showing polyethylene dimensions and ^{3}He tube locations.

The detector efficiency is defined as the response from a pair of detectors 134 cm apart to a ^{252}Cf source placed in the center between the slabs. A design goal of at least 4% efficiency was selected to enable coincidence counting techniques to be used effectively. Related to this performance criteria is the practical requirement that the mapping of the glove box needs to be done in a reasonable amount of time (that is, the fewest number of discrete positions along the glove box that still yields acceptable results). The combination of these goals results in the dimensions shown in Fig. 2 and characteristics summarized in Table I.

TABLE I. Summary of Detector Characteristics

Height	160 cm
Width	7.6 cm
Length	100 cm
Number of ^{3}He tubes	20 (per slab)
Tube active length (model)	152 cm (RS-P4-0860-201)
Efficiency	5.9% (w/polyethylene curtain) 4.9% (w/o curtain)
Die-away time	63 µs

The efficiency of the detector system was measured at the Los Alamos National Laboratory, where the leaded Plexiglas shield was replaced with an equivalent moderating thickness of high-density polyethylene. This polyethylene curtain was hung from the detector junction box, adding an additional 2.5 cm of thickness to the detector slab. Shorter versions of these curtains will be used for areas of the glove box not covered by the Plexiglas shield. Figure 3 is a photograph of a set of detectors at the Los Alamos test facility with the polyethylene curtains in place. In between the slabs is a glove-box mock-up to simulate some of the scattering effects that will occur in the actual glove box. The die-away time for these detectors is somewhat longer than other polyethylene-moderated instruments because of the lack of an inner cadmium lining, which is typical of other systems. The absence of cadmium on the glove-box side of the detector is required because of the use of the Plexiglas shield as part of the detector design to meet the efficiency requirement.

The spatial response function of the GBAS instrument was characterized by moving a ^{252}Cf source along each axis centered between the slabs, and by the generation of a response surface corresponding to the summation of the two axes parallel to the slab detectors. Figures 4 and 5 compare the Monte Carlo generated coincidence response curve with the actual measured data for the vertical (z-axis) and horizontal (x-axis) directions. The measured data are plotted as discrete points. As can be seen from both figures, the calculated and measured data generally agree with the measured statistics (~2%).

Fig. 3. Photograph of glove-box assay system (GBAS-1) showing electronics rack, housing computer and JSR-11 coincidence package, detector slabs with polyethylene curtain attached, and mock-up glove box at the Los Alamos test facility.

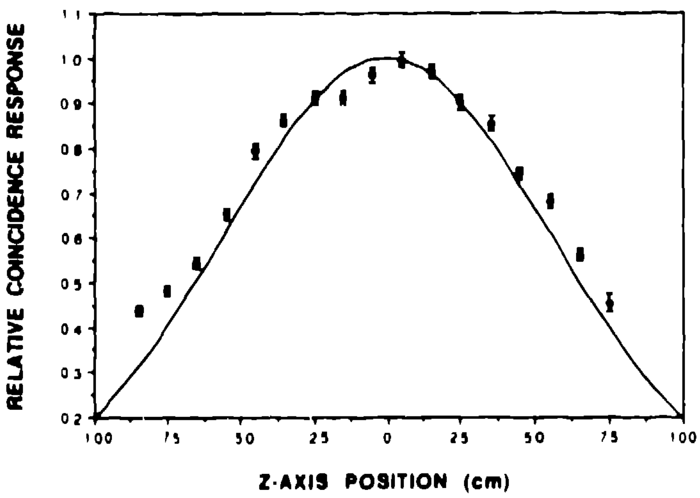

Fig. 4. Coincidence response for vertical (z-axis) displacement of ^{252}Cf source. Curve is MCNP-generated simulation and points are actual measured data.

Combining the response functions for both axes yields the surface shown in Fig. 6, for the case of a 3-m-high by 3-m-long glove box and six measurement positions. Each position is approximately one full-width-at-half-maximum distance from the neighboring position. For material located in the center of the glove box (y = 0 plane), the geometric variation of the response function is within ±10% over most of the glove-box volume where plutonium is expected to be located. When the physical location of the process equipment is taken into account, the effective area of "flatness" is ~80%, with the region at the bottom of the glove box being the most likely region where holdup might be located outside of the ±10%

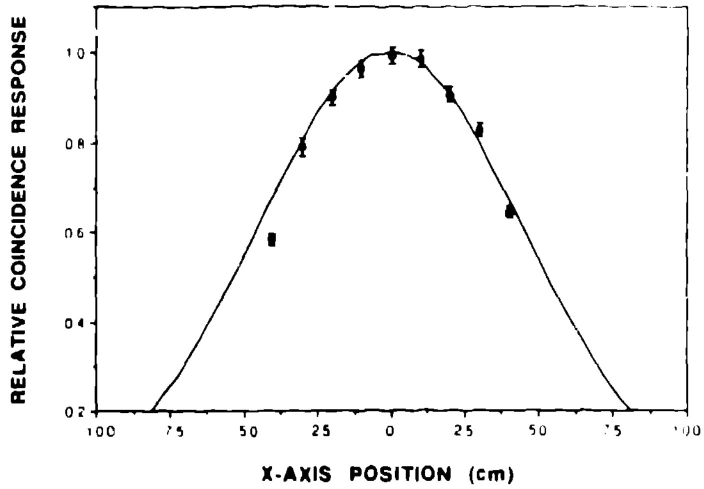

Fig. 5. Coincidence response for horizontal (x-axis, parallel to detectors) displacement of ^{252}Cf source. Curve is MCNP-generated simulation and points are actual measured data.

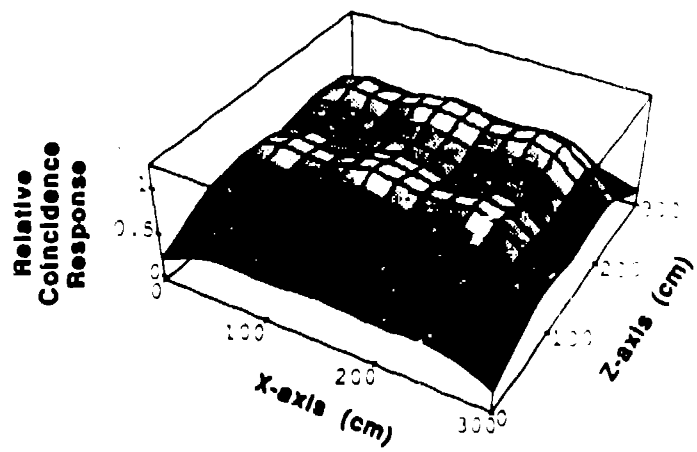

Fig. 6. Coincidence response surface for source movement in the horizontal-vertical plane (78 plane).

zone. Again, the automated nature of the PFPF process benefits the measurement by generally encasing the process equipment that is most likely to contain plutonium holdup. Confining the material results in the holdup areas being more localized. Figure 7 shows a top view of the response function surface with shaded areas representing a response of at least 0.9 relative coincidence count rate. Material displacement along the axis perpendicular to the slabs (y-axis) results in an increase in detector efficiency because of an increase in the overall solid-angle. This is a <10% effect for displacements of ±20 cm from the center line. A correction for this increase may be made by analyzing the totals rate from each detector individually. Much of this effect will be reduced during the actual instrument use because the plutonium will be distributed over a volume rather than being in discrete points.

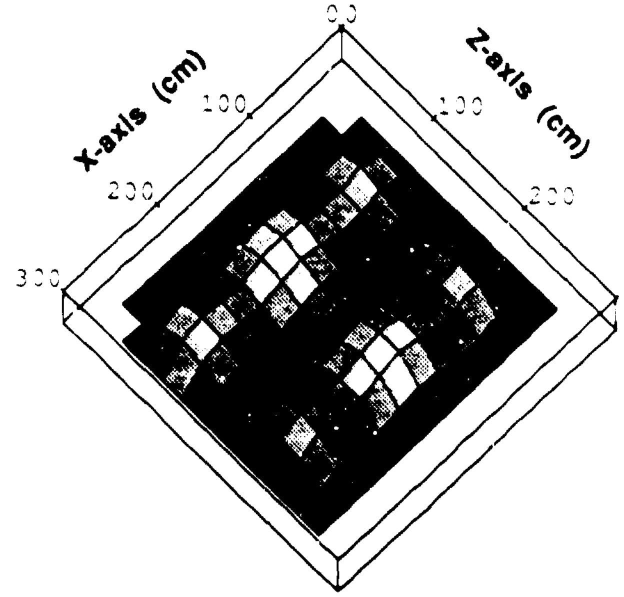

Fig. 7. Top view of coincidence response surface showing locations where the relative coincidence response is 0.9 or greater.

MEASUREMENT APPROACH AND CALIBRATION

The intimate coupling of the detector response function and movement over the glove box define the basis for the measurement approach. The position matrix to be used depends on the size of the glove box. There are two vertical positions for a 3-m-high glove box and one horizontal position for each meter of glove box length. The particular position matrix (for example, 2 x 6 for a 3-m by 6-m glove box) is part of the calibration and therefore a given glove box will always be mapped out with the same number of positions. To map out the coincidence response from the glove box, the detectors are placed in specially designed lifters and are positioned on both sides of the glove box. After completion of a count at a given position, the detectors are moved in unison to the next position and counting resumes. This process is repeated until all positions in the matrix are measured. Facilitating this data acquisition is software developed specifically for holdup measurements in which the sample is larger than the detector (in this case, a glove box). The user chooses how long to remain at a given position, allowing areas of the glove box containing more plutonium material to be measured longer. After data acquisition is terminated at a matrix position, a 3-σ test is performed that tests for outliers. When the entire glove-box measurement is completed, the data are taken to the inspection room and reviewed. As a part of this review, the entire data set for a glove box is condensed into an equivalent data set for a single measurement. This is done so that the next step, transfer to the IAEA program HLNC for conversion to grams of plutonium, can be accomplished correctly.

Calibration of the GBAS instruments will be performed at the PFPF facility in June 1990. This calibration effort will consist of mapping out the coincidence response of each glove box needing to be measured. Initial data will be a measure of the existing plutonium content of the glove box. One or two standards containing 500 g of plutonium will then be placed in the glove box near the existing holdup and the glove box mapped out in the same manner. This "add-a-gram" technique will be repeated several times. Figure 8 shows a typical glove-box configuration and measurement matrix. The number and location of matrix positions used in the calibration must also be used for routine measurement, and as such the calibration procedure defines the position matrix to be used by the software during normal use of the GBAS instrument.

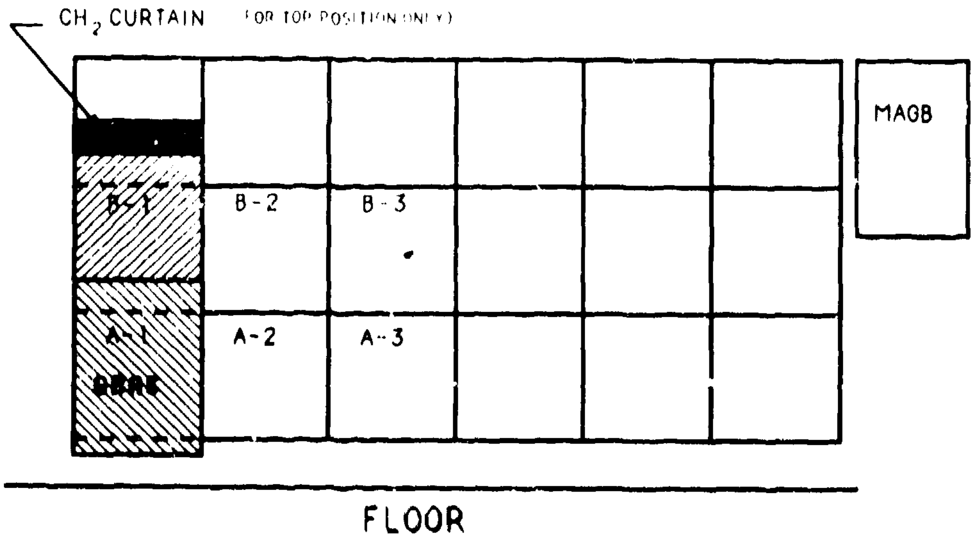

Fig. 8. Schematic of glove box with position matrix labeled. Measurements made at the upper position (row B) use a polyethylene curtain to compensate for the lack of the Plexiglas shielding.

SUMMARY

The ability of inspectors to measure in-process materials in the form of holdup greatly enhances safeguards effectiveness by extending their measurement capability to all materials in the facility. With the inclusion of glove boxes in the sample inventory, all the material in the plant is subject to the sampling plan. The measurement approach taken is versatile, lending itself toward application to other facilities and types of samples. The ability of nondestructive-assay equipment to take advantage of aspects of automated plant design improves assay accuracy. The use of Monte Carlo calculational techniques provides a convenient and accurate method for detector design and, in this case, optimization of the measurement approach. Measurements made with the GBAS system over time will enable the monitoring of plutonium accumulations at specific locations in the facility.

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